CORPS OF ENGINEERS, U. S. ARMY

MISSISSIPPI RIVER COMMISSION

WAVE ACTION AND BREAKWATER LOCATION EAST BEAVER BAY HARBOR, LAKE SUPERIOR, MINNESOTA

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-295

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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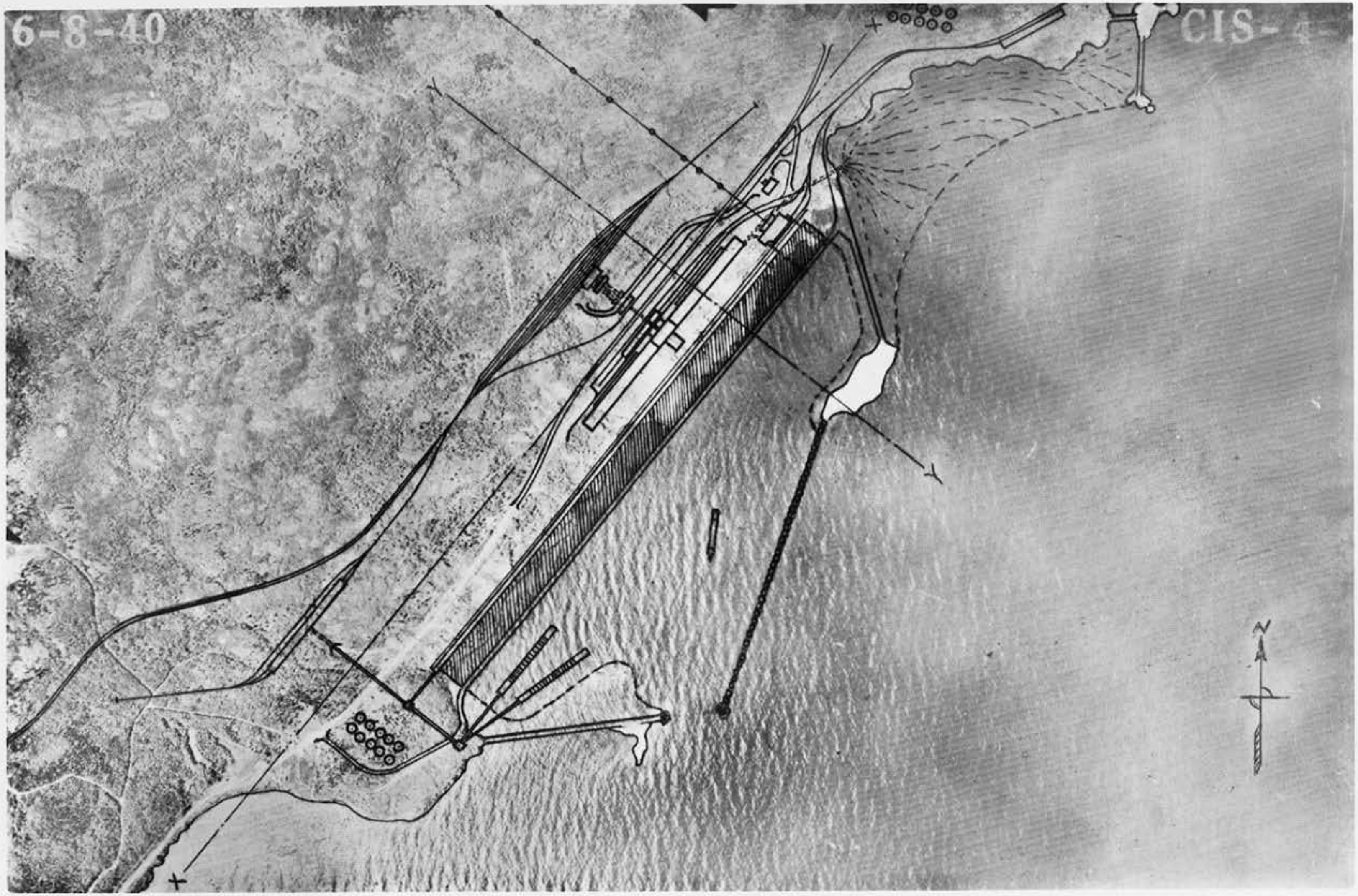

FRONTISPIECE. Proposed ultimate plant and harbor development, East Beaver Bay, Minnesota

PREFACE

The Oglebay Norton and Company, Cleveland, Ohio, in a letter dated 30 June 1947, requested the Waterways Experiment Station to conduct a hydraulic model investigation of the proposed East Beaver Bay harbor. Authority to perform the investigation was granted by the Chief of Engineers, U. S. Army, 28 July 1947.

The investigation involved (1) study of problems relating to the over-all harbor design, and (2) study of the stability of the proposed rubble breakwaters. This report is concerned with the harbor-design phase of the investigation only; stability tests of the proposed breakwaters are described in Technical Memorandum No. 2-296, July 1949.

The model tests described herein were conducted during the period from August 1947 to August 1948. Engineers of the Experiment Station actively connected with the investigation were Messrs. E. P. Fortson, Jr., F. R. Brown, R. Y. Hudson, R. A. Jackson, H. B. Wilson, and H. A. Bell, Jr. Prior to undertaking the investigation, an engineer of the Experiment Station inspected the prototype site.

Active in liaison capacities were Messrs. H. J. Taylor, F. J. Smith, C. A. Arnold, and D. S. Young of the Oglebay Norton and Company; Mr. I. H. Wynne of the Reserve Mining Company; Mr. C. L. Kingsbury of the American Rolling Mill Company; Mr. E. T. Davis of the Wheeling Steel Corporation; Captain H. F. Wiersch of the Columbia Transportation Company; and Dr. L. G. Straub, Director, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minn., who attended conferences at the Waterways Experiment Station and witnessed model demonstrations.

CONTENTS

SUMMARY

A hydraulic model study was performed of the proposed harbor at East Beaver Bay, Minnesota, to determine the adequacy of the initially proposed plans of harbor construction in protecting the docks from storm-wave action, and to devise a satisfactory plan if the initially proposed plans were found inadequate. It was especially desired that the adopted plan afford optimum protection to the docks at minimum cost. The harbor study was conducted using a 1:150-scale concrete model geometrically similar to its prototype.

It was concluded from the results of the model study that: (1) the originally proposed harbor plan with a 930-ft navigation opening immediately south of Pancake Island would not afford adequate protection to the docks and ships within the harbor, and would not provide safe navigation entrance conditions; (2) the originally proposed harbor plan with a 600-ft navigation opening on the south end of the harbor immediately west of Gull Island would provide adequate protection if spending beaches were added in critical areas of the harbor, and if the breakwater leg from Pancake Island to shore were constructed with a straight alignment and a crown elevation of at least +14 ft lwd; and (3) the best breakwater plan tested involved a navigation opening 600 ft wide located immediately east of Gull Island.

WAVE ACTION AND BREAKWATER LOCATION

EAST BEAVER BAY HARBOR, LAKE SUPERIOR, MINNESOTA

Model Investigation

PART I: INTRODUCTION

1. The investigation reported herein was occasioned by plans of the Oglebay Norton and Company for construction of an ore-processing plant on the rugged north shore of Lake Superior about 45 miles northeast of Duluth, Minnesota, and about 2 miles northeast of the small village of Beaver Bay, Minnesota. A harbor will be required to provide berthing space and protection from storm waves for ships servicing the plant and transporting processed ore to industrial cities along the southern shores of the Great Lakes. Plate 1 shows the general location of the proposed plant and the character of the shore in the immediate vicinity of East Beaver Bay. The fact that water of extreme depth prevails along the north shore of Lake Superior made the selection of a harbor site and the design of the harbor and harbor breakwaters unusually difficult.

2. The site of the proposed harbor is exposed to wind waves generated by storms from all directions clockwise between northeast by east and southwest. These limiting directions are determined by the general shape of Lake Superior and the location of the proposed harbor with respect to the lake shores. Storms occur more frequently from the general directions of northeast and southwest. Storms of appreciable magnitude do not occur very often from the directions east, southeast and south.

Also, the fetch distances in the directions southeast to south are small. Thus, the directions northeast by east to east and southwest to south-southwest are the most critical with respect to storm winds.

3. At the beginning of the model study, the tentative plans of harbor design were similar to those designated plans 1 and 2 (plates 2 and 3) of this report. From a cost-of-construction standpoint, plan 1, with the navigation entrance located in the deep-water area immediately south of Pancake Island, was the most desirable. Plan 2, with the navigation opening in the south end of the harbor between Gull Island and the shore, was the alternate plan designed for possible use in the event the plan-1 navigation entrance proved unsatisfactory. The crown elevation of the breakwaters was +8.4 ft lwd for both tentative plans. The original design of the breakwater cross section (plate 2) was evolved from consideration of the fact that, since adequate rock quarries would be available at the shore ends of both breakwater arms, the end-dump method of construction could be used thus effecting considerable savings over the more common construction method in which the rubble is dumped from floating equipment.

4. The model study was performed to determine which of the originally proposed plans would provide the greatest protection to the harbor from wave action, and whether the degree of protection provided would be adequate. If it were found that the protection provided by the best of the two tentative plans was inadequate, it was desired that an adequate plan be devised. Also, it was desired that the plan provide maximum possible protection at the least possible cost. It was considered that a hydraulic model study was the best means to insure an understanding

and integration of the complex and interdependent factors involved in development of the harbor plans.

PART II: DEFINITION OF PERTINENT TERMS

5. All quantities, both model and prototype, are expressed in terms of prototype equivalents, except where otherwise stated. Various terms used throughout the investigation are defined below.

Depth, elevation. All water depths, hydrographic contours and breakwater elevations are referred to low water datum for Lake Superior (lwd = 601.6 ft above mean tide at New York City). All topographic contours and elevations are in feet referred to mean tide at New York City.

Wave length. Wave length is the horizontal distance from crest to crest, or trough to trough, of two successive waves.

Wave height. Wave height is the vertical distance from trough to crest of a wave.

Wave period. Wave period is the time between the passage of two successive wave crests by a given point; that is, the time in which a wave travels one wave length.

Fetch. Fetch is the distance across open water, measured from the windward shore, over which the wind blows.

Seiche. Seiches are standing gravity waves of relatively long periods which oscillate in lakes, canals, bays and along open seacoasts. Most lake seiches are caused by sudden or intermittent-periodic changes in atmospheric pressure and wind velocity.

Model-prototype scale. The ratio of model dimensions to corresponding prototype dimensions.

Spending beach. A sloping beach or harbor structure whose angle of inclination is such that waves break on the slope and dissipate their energy by turbulence.

PART III: THE MODEL

Design

6. The linear scale of the harbor model was selected from consideration of such factors as the absolute depth of water in the model required to prevent appreciable frictional resistance and surface-tension effects, absolute size of model waves, available space, available wave-generating and measuring apparatus, cost of construction and ease of model operation. Because of the effect of depth and wave length on wave refraction for short-period wind waves, it was necessary to use a geometrically undistorted model. After the linear scale had been selected, the model was designed in accordance with Froude's[1] model laws. Based on these model laws, a linear scale of 1:150, and a specific weight scale of 1:1, the following scale relationships were derived:

Characteristic	Dimension[2]	Model-Prototype Scale
Length	L	L_r = 1:150
Area	L^2	$A_r = L_r^2$ = 1:22,500
Volume	L^3	$\bar{V}_r = L_r^3$ = 1:3,375,000
Time	T	$T_r = L_r^{1/2}$ = 1:12.25
Velocity	L/T	$V_r = L_r^{1/2}$ = 1:12.25
Specific Weight	F/L^3	γ_r = 1:1
Unit Pressure	F/L^2	$P_r = L_r \gamma_r$ = 1:150

1 ASCE Manual of Engineering Practice, Number 25, "Hydraulic Models," pp 9 and 43.

2 In terms of force, length and time.

Characteristic	Dimension[2]	Model-Prototype Scale
Force	F	$F_r = L_r^3 \gamma_r$ = 1:3,375,000
Weight	F	$W_r = L_r^3 \gamma_r$ = 1:3,375,000
Energy	FL	$E_r = L_r^4 \gamma_r$ = 1:506,250,000

Description

7. The model, constructed of concrete, was an accurate replica of the proposed prototype harbor area. It reproduced a sufficient area -- 6,000 sq ft, equivalent to 4.8 sq mi in the prototype -- up and down shore and lakeward to permit generation of waves from the critical wind directions (see photograph 1 and plate 1). All breakwaters and docks were constructed in the model of concrete.

8. Model waves were generated by two movable, plunger-type wave machines; one may be seen in the background of photograph 1. The machines, which were 40 ft and 20 ft in length (model dimensions), were moved from one position to another on the model to generate waves from different directions. Waves were reproduced in accordance with the same scale ratios as those used for model construction. Generation of the waves was accomplished by the periodic displacement incident to the vertical movement of the plungers in water.

9. Wave heights in the model were measured with a wave-height gage designed and constructed at the Waterways Experiment Station especially for this purpose. The gage consists of series-connected resistors installed in a direct-current circuit with the resistors so calculated that the current varies directly with submergence of the gage in water. The results were recorded on sensitized paper by means of an oscillograph.

PART IV: THE TESTING PROGRAM

Selection of Test Conditions

Water level

10. As shown by the Lake Survey records,[3] the water level of Lake Superior varies from year to year and season to season. The seasonal variation is periodic, with the highest lake levels occurring in the late summer and fall months and the lowest levels in the spring months. In addition to the seasonal variations, lake-seiche oscillations cause periodic changes in local water levels with periods ranging from a few minutes to several hours. Seiche oscillations, which are generated by sudden changes, or a series of intermittent-periodic changes, in atmospheric pressure and similar changes and variations in wind velocity, are capable of causing relatively large surge currents in harbors. Surges due to seiches are also capable of causing troublesome movements of vessels moored to piers in harbors. However, because seiches of appreciable amplitude do not occur frequently in the Great Lakes, the problem at East Beaver Bay was considered to be one involving, principally, the effects of surface wind waves, and no attempt was made to reproduce seiche oscillations in the model for this study.

11. All model tests in this investigation were conducted using a still-water level of +1.5 ft lwd. This selection was based on the average, monthly mean level of Lake Superior, which is +0.5 ft lwd, with 1.0

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3 "Monthly Mean Water Levels of the Great Lakes, 1860-1949." From official records of the U. S. Lake Survey, CE, Detroit, Michigan.

ft added for the average effects of wind and seiche action on the local water level during storms. Thus, the value of +1.5 ft lwd represents an estimate of the average elevation of the water surface of Lake Superior in the immediate vicinity of East Beaver Bay during storms of sufficient intensity and of such direction that protection of the proposed harbor from wave action would be necessary.

Wave characteristics

12. Based on considerations already discussed in paragraph 2 and on the location and alignment of the proposed navigation openings into the harbor, waves from the directions east by north and southwest were selected for use in determining the relative advantages and disadvantages of the various improvement plans tested. The maximum waves which can be expected from the selected directions were estimated to be about 22 ft x 370 ft and 12 ft x 185 ft from the directions of east by north and southwest, respectively. Waves of these proportions were used for testing all the proposed plans of harbor improvement except plan 2B. For plan 2B a smaller size storm wave was used to simulate more closely average storm-wave conditions. The maximum storm waves, rather than the average size storm waves, were used for testing because it was easier to measure the larger waves on the small-scale model and to discern the effects of relatively minor changes in the elements of a particular plan.

13. Near the completion of the harbor study, the results of a prototype wind-wave analysis[4] became available. This analysis revealed

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[4] The wind-wave analysis is described in detail in T.M. No. 2-296, "Breakwater Stability, East Beaver Bay Harbor, Lake Superior, Minnesota; Model Investigation," Waterways Experiment Station, July 1949.

that the maximum storm waves which occurred during the 33-year analysis period were within the same order of magnitude as those previously estimated and used for model testing. It was found that the largest waves which occurred were about 16 ft x 260 ft and 12 ft x 210 ft in size from the directions of northeast and southwest, respectively, and that the critical storm directions for the proposed East Beaver Bay Harbor are the directions northeast to east and southwest.

Breakwaters

14. All tests in which wave heights were measured and recorded were conducted with the crown of the model breakwaters arbitrarily raised sufficiently to prevent overtopping. In this way the effectiveness of different plans, and the effects of minor variations in the elements of a particular plan, could be determined more accurately. The optimum breakwater heights for each breakwater plan were estimated from observational tests. In these tests the crown elevations were reproduced to scale, but the pervious rubble breakwaters were reproduced of impervious concrete. Thus, the overtopping which occurred in the model exceeded that which would obtain in the prototype. This fact was taken into consideration when the optimum breakwater heights were selected.

Description of Plans Tested

15. Tests were performed on seven plans of harbor improvement (plans 1, 2, 2A, 2B, 3, 3A, and 4), the elements of which are shown on plates 2 to 6. Present development plans for the ore-processing plant provide for the completion of the plant and adjoining wharf in stages.

The initial stage involves a wharf front 2,720 ft in length. When completed the wharf will be 6,750 ft in length. The harbor was tested in the model using both the initial and ultimate wharf developments. Plans 1, 2, 2A and 2B simulated the initial stage, and plans 3, 3A, and 4 the ultimate. The breakwaters in all plans except plan 4 were rubble-mound structures exclusively. In plan 4, however, the breakwater leg between Pancake Island and the navigation opening was a vertical-walled cellular structure surmounting a mound of ore-plant tailings. In plan 1 the navigation opening was 930 ft wide and located in the deep-water area immediately south of Pancake Island. In plans 2, 2A, 3 and 3A the navigation opening was located west of Gull Island and was 600 ft wide in plans 2 and 3 and 930 ft wide in plans 2A and 3A. The plan-4 navigation opening was located immediately east of Gull Island and was 600 ft wide. The purpose of plan 2B was to determine the degree of protection provided by a partially completed breakwater plan, and for these tests 2,400 ft of the plan-2 breakwater between Gull and Pancake Islands was omitted. The realigned north breakwater leg between Pancake Island and shore and the spending beach feature of plan 3 had been installed in the model when tests of the plan-2B breakwater were conducted.

PART V: RESULTS OF MODEL TESTS

Presentation and Interpretation of Test Results

16. The results of the wave-action study are presented on plates 7 to 18. The wave-height contour data presented on these plates were obtained at gaging stations located at 2-ft intervals (model dimension) over the harbor area. When interpreting these data it should be remembered that the waves resulting in the model harbor for each plan and test-wave condition were about twice as large as those which would result from the average storm-wave condition in the prototype. This is true for all tests except those of plan 2B where model waves of a size more nearly equivalent to average storm-wave conditions were used. The frequency of occurrence of storm waves from the northeast to east compared with the number of storms from the south to southwest directions, as determined by the prototype wind-wave analysis discussed in paragraph 13 (about 4 to 1 for waves above 5 ft in height), should also be taken into consideration.

17. When it was necessary to raise the crown elevation of the breakwater to prevent overtopping (paragraph 14), a crown elevation of +44 ft lwd was used. This elevation had no special significance other than the fact that an elevation of approximately +44 ft lwd was required to provide absolute protection from overtopping for the larger primary waves used in the model tests.

Discussion of Results

Plan 1 (plate 2)

18. No wave-height contour data were secured for this plan because,

after observing the action of the plan-1 breakwater during a model demonstration, representatives of both the Oglebay Norton and Company and the Waterways Experiment Station agreed that testing of the plan should be discontinued. It was decided that the navigation opening, although suitably located with respect to economic considerations, allowed too much wave energy to enter the harbor, especially for waves from the east by north direction, and was not positioned satisfactorily with respect to navigation entrance conditions.

Plans 2 and 2A (plate 3)

19. The wave heights in the harbor as shown on plates 7 to 10 are indicative of the amount of wave action which resulted from waves passing through the navigation openings of these plans. Photograph 1 illustrates the over-all harbor conditions for plan 2A with test waves from the east by north direction. Test results indicate that plans 2 and 2A would be satisfactory, with respect to the amount of wave energy entering the navigation opening, for all conditions except when severe storms occurred from the southwest direction. In the latter case it is thought that a navigation opening larger than 600 ft (as in plan 2A) would allow more wave action in the harbor than could be tolerated. Good entrance conditions would be provided by the navigation openings of both plans. The desirable features of these plans were the favorable location for the navigation opening and the existence of a spending beach which composed a large portion of the shore-line boundary of the harbor. From observational tests using different elevations for the breakwater crown it appeared that the +8.4 ft lwd crown contemplated for the rubble breakwaters

would be inadequate for that portion of breakwater between Pancake Island and shore. The corners formed inside and outside the harbor by the intersection of the wharf and breakwater at the northeast end of the wharf were found to result in unfavorable concentrations of wave energy. Consequently, it was decided that the breakwater leg between Pancake Island and shore should have a straight alignment, the crown elevation of this portion of breakwater should be raised to at least +14 ft lwd, and a spending beach should be created inside the harbor area in the corner formed by the northeast end of the wharf, the railroad fill and the breakwater. These features were incorporated in the elements of plans 2B, 3, 3A, and 4.

Plan 2B (plate 4)

20. Plan 2B, having a 2400-ft gap in the reach of breakwater between Gull and Pancake Islands, was tested to determine the amount of protection which would be afforded by a breakwater plan completed except for the deep-water portion. The results of these tests (plates 11 and 12) showed that the partial breakwater would provide adequate protection from waves from the southwest direction. However, very little protection would be provided ships in the area between Pancake Island and the wharf for storm waves from the east to northeast directions. During storms from these directions, safe anchorage conditions would exist only in a small area in the northeast corner of the harbor near the artificial spending beach.

Plans 3 and 3A (plate 5)

21. Test results of these plans are shown by wave-height contours

on plates 13 to 16. By comparing these results with those of plans 2 and 2A (plates 7 to 10), the effect of a vertical-walled wharf extending the full length of the harbor can be ascertained. The heights of waves which impinge on vertical-walled structures are amplified by reflection, and the reflected waves act as additional sources of energy, tending to propagate waves into portions of the harbor which would otherwise be afforded protection. With storms from the east by north direction, reflected waves from the wharf immediately inside the navigation opening would make navigation conditions at the entrance more dangerous than with the plan-2 opening. The results of these tests showed that the efficacy of this type breakwater and navigation opening would be considerably reduced after completion of the ultimate plant and wharf development. This would be especially true for the wider (930-ft) navigation opening of plan 3A. From a study of the results of tests on plans 3 and 3A, it was decided that artificial spending beaches around the inside perimeter of the harbor would be necessary to counteract the deleterious effects of the vertical-walled wharf in the ultimate plant development.

Plan 4 (plate 6)

22. Results of tests of plan 4 are shown on plates 17 and 18. Photograph 2 illustrates the over-all harbor conditions for the plan with test waves from the southwest direction. Consideration of a breakwater plan with a large portion of the breakwater situated in deep water was brought about by the following factors: (a) the results of tests on previous plans had shown the need for more spending beaches to offset the detrimental effects of the ultimate wharf development, and the

advisability of positioning the navigation opening farther from the dock face to provide more area in which entering waves could expand before reaching the dock; (b) the possibility of constructing the portions of rubble breakwater from shore to Gull Island and from shore to Pancake Island at the time the initial plant and wharf development was constructed, then adding the deep-water portion of the breakwater from ore tailings as they become available; and (c) the plan-4 breakwater alignment provided a very good location for the navigation opening with respect to the most critical storm-wave directions. Also, when finally completed, the plan-4 breakwater alignment would provide a larger area of protected harbor.

23. The test results (plates 17 and 18) show that plan 4 would be very effective in protecting the ultimate wharf development from storms from the east by north direction. Like the other plans tested, plan 4 would be more effective as the wave direction shifts toward the northeast. Plan 4 would be only slightly more effective than plan 3 in protecting the wharf from waves from the southwest; however, the plan-4 arrangement would provide safe anchorage conditions in each end of the harbor during storms from that direction. The plan-4 spending beaches were very effective in reducing wave action in the harbor considering the fact that this plan has such a large portion of its inside boundary composed of vertical-wall structures. Without the spending beach immediately north of Gull Island, it would be impossible to utilize efficiently the extra loading piers provided by this plan.

24. Observational tests to investigate overtopping showed that the rubble breakwater between Pancake Island and shore should be

constructed with a crown elevation of at least +14 ft lwd; that, unless absolute protection from overtopping is required, a crown elevation of from +8 to +10 ft would be adequate for the rubble breakwater between Gull Island and shore; and that the cellular breakwater between Pancake Island and the navigation opening would provide sufficient protection from overtopping with a crown elevation as high as +8 to +10 ft lwd.

25. Navigation conditions at the entrance to the plan-4 harbor would be very good except when storms approach the harbor from the southeast to east directions. The prototype wind-wave analysis showed, however, that intense storms from the directions south to east are very rare.

PART VI: CONCLUSIONS

26. Based upon the results of the model tests, it was concluded that:

a. The breakwater between Pancake Island and shore should have a straight alignment, should be constructed with a crown elevation of at least +14 ft lwd, and should be aligned so as to allow sufficient space for an artificial spending beach between the northeast end of the wharf, the proposed railroad fill, and the breakwater.

b. To counteract the detrimental effects of the long vertical-walled wharf and proposed cellular breakwater on reflected wave action in the harbor, artificial spending beaches should be formed around as much of the inside harbor perimeter as is practical.

c. A crown elevation of from +8 ft lwd to +10 ft lwd will be sufficient for the breakwater leg between Pancake Island and the navigation opening of plan 4 (or between Pancake Island and Gull Island for the other plans), and the breakwater leg between Gull Island and shore.

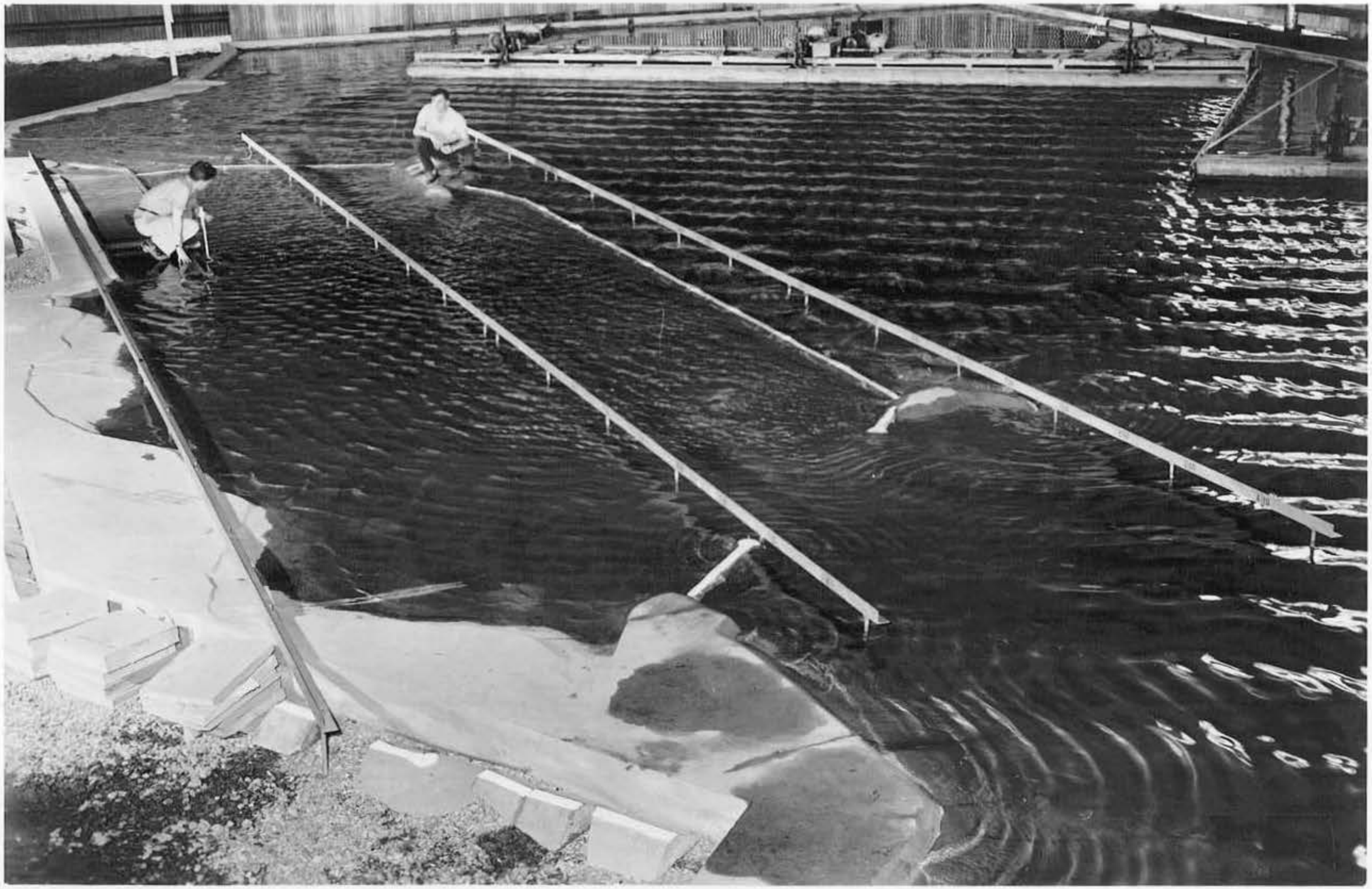
d. The best navigation opening location tested was that of plan 4 where the opening was positioned immediately east of Gull Island.

e. The width of the navigation opening should be as small as ships' masters will allow (possibly 600 ft) because of the large number of reflective surfaces around the inside perimeter of the proposed harbor.

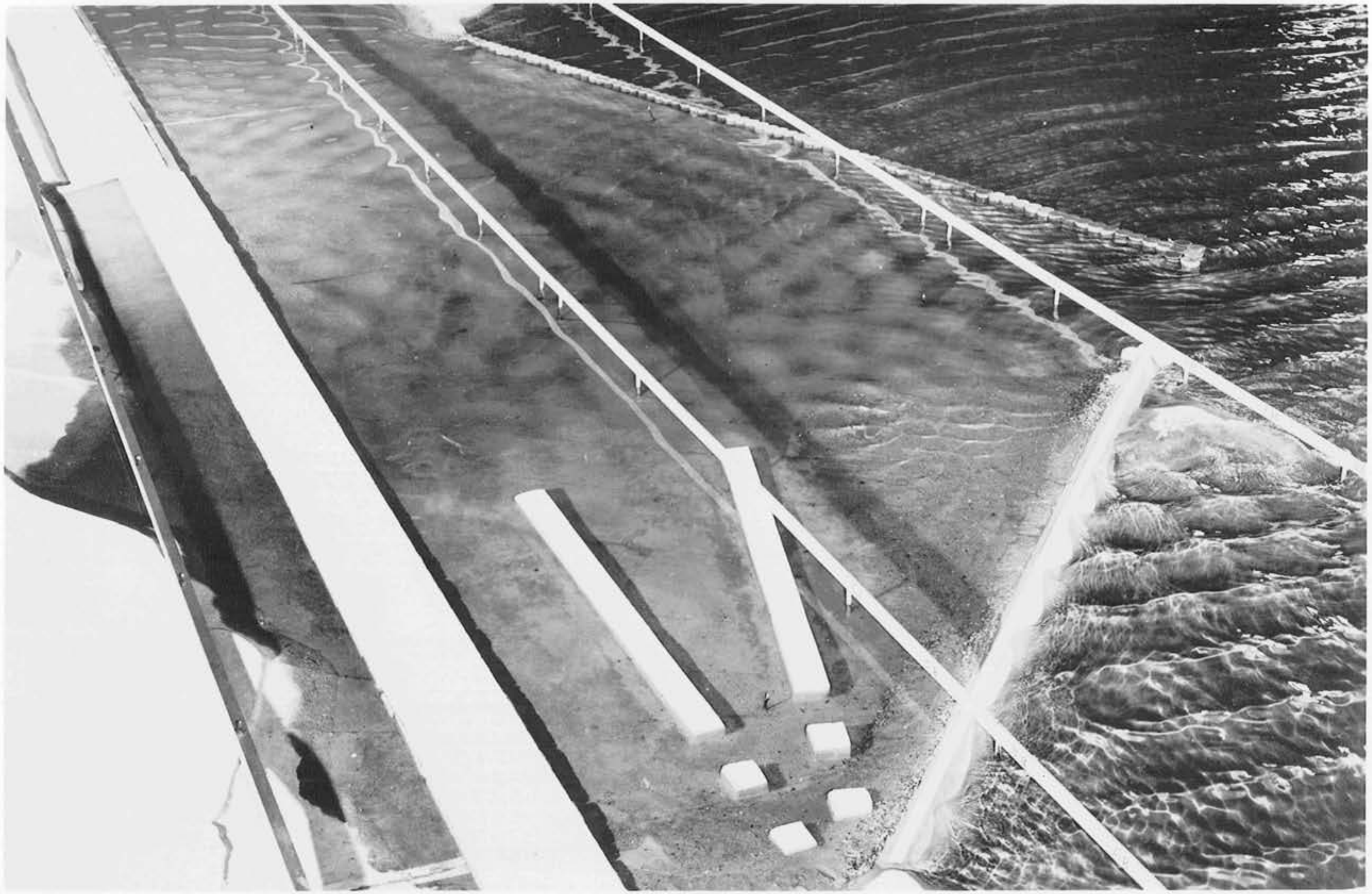
f. For the ultimate plant and wharf development, the breakwater alignment and spending-beach elements of plan 4 are the most efficient.

PHOTOGRAPHS

PHOTOGRAPH 1



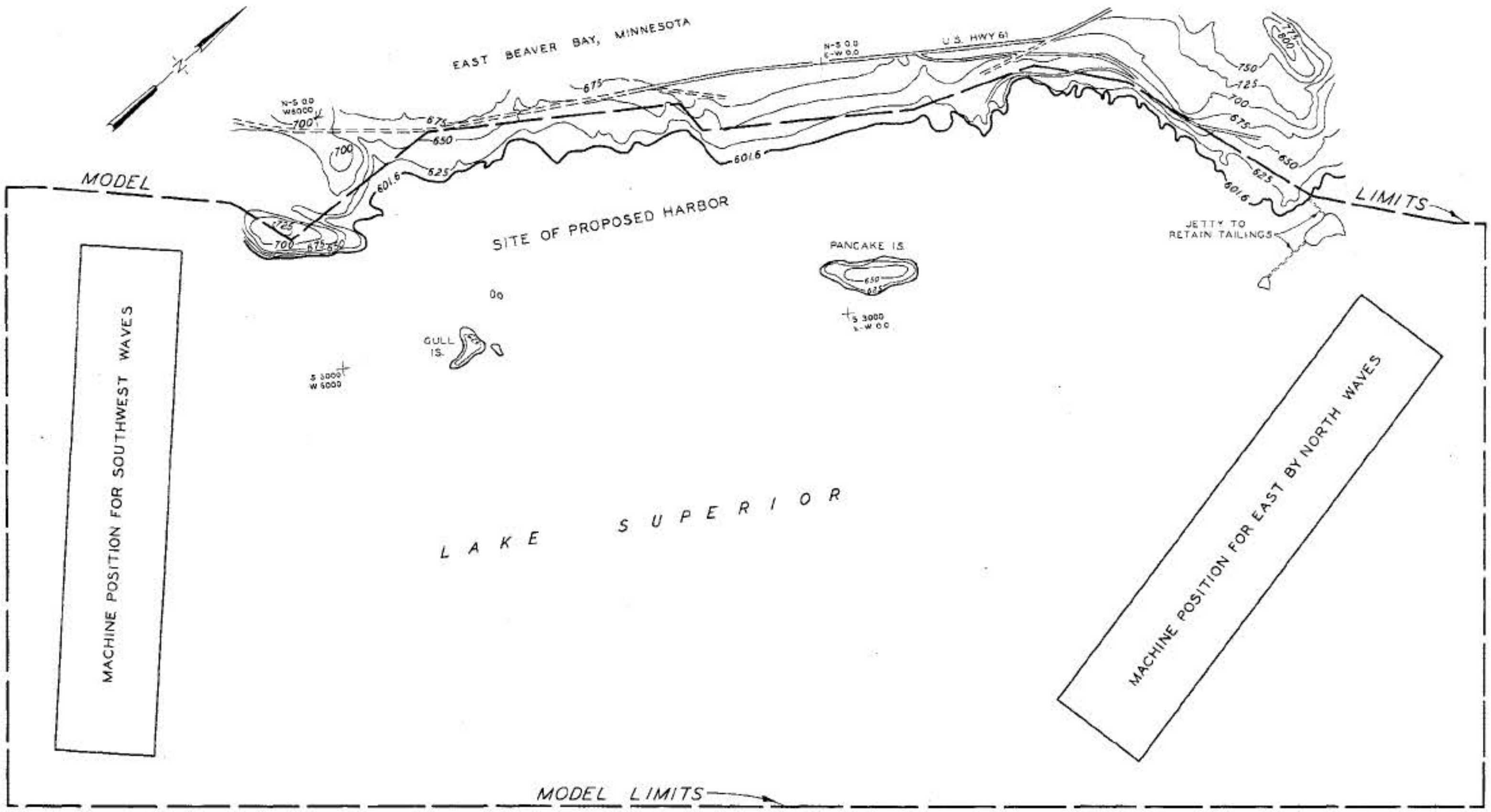
Plan 2A: 22-ft waves from east by north direction



Plan 4: 12-ft waves from southwest direction

PHOTOGRAPH 2

PLATES



NOTE: TOPOGRAPHIC CONTOURS ARE IN FEET REFERRED TO MEAN TIDE AT NEW YORK CITY. 601.6 CONTOUR = LOW WATER DATUM SHORE LINE.
PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

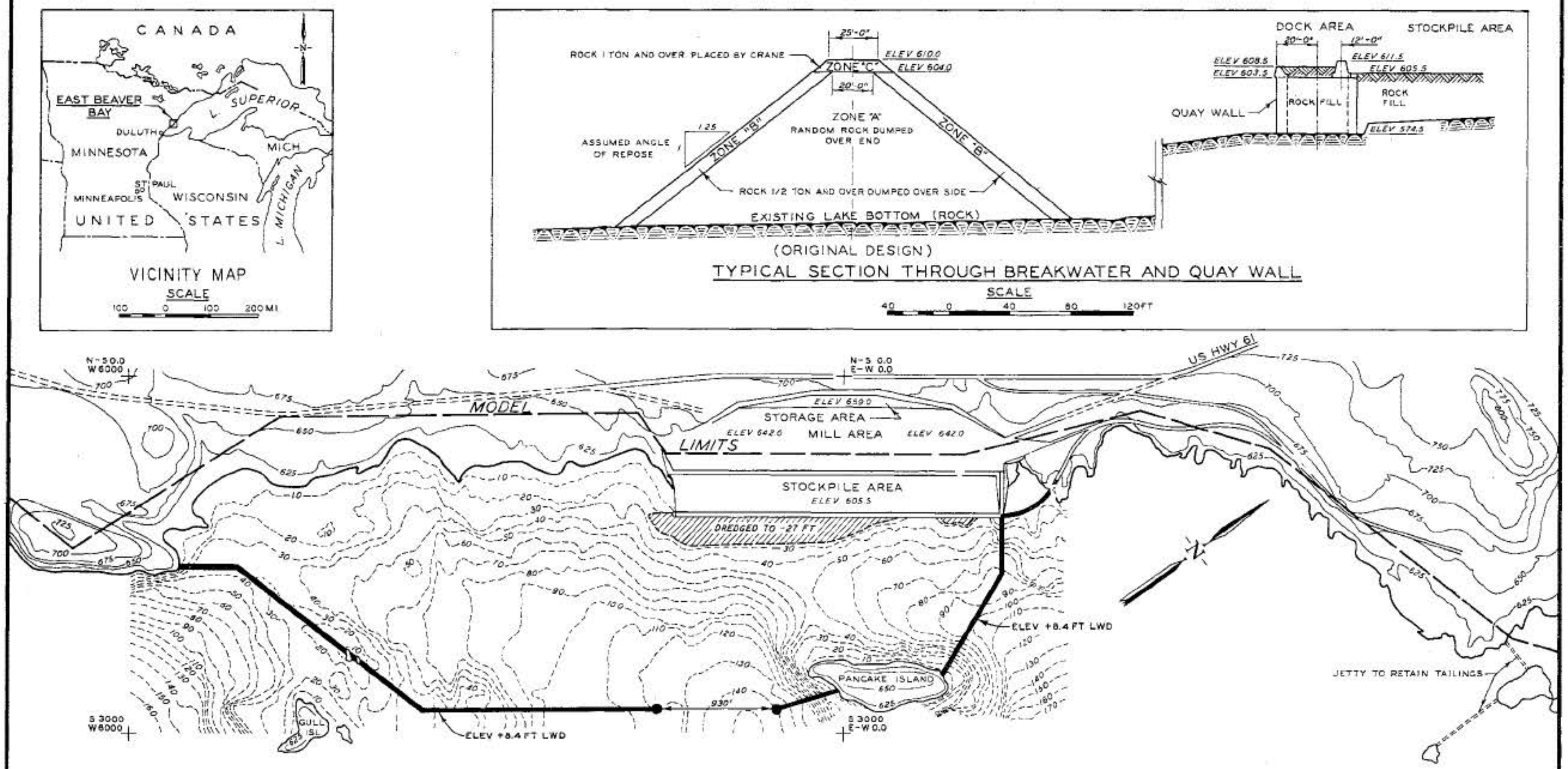
LOCATION MAP AND MODEL LIMITS

SCALES

PROTOTYPE 500 0 500 1000 1500 FT

MODEL 3 0 3 6 9 FT

PLATE 1



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LEGEND

PROPOSED RUBBLE-MOUND BREAKWATER

PROPOSED DREDGING. PROJECT DEPTHS AS SHOWN

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

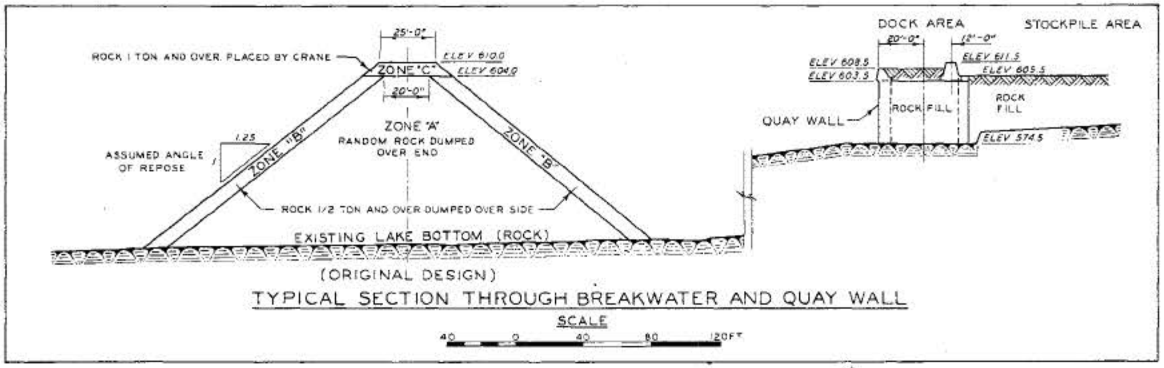
ELEMENTS OF PLAN 1

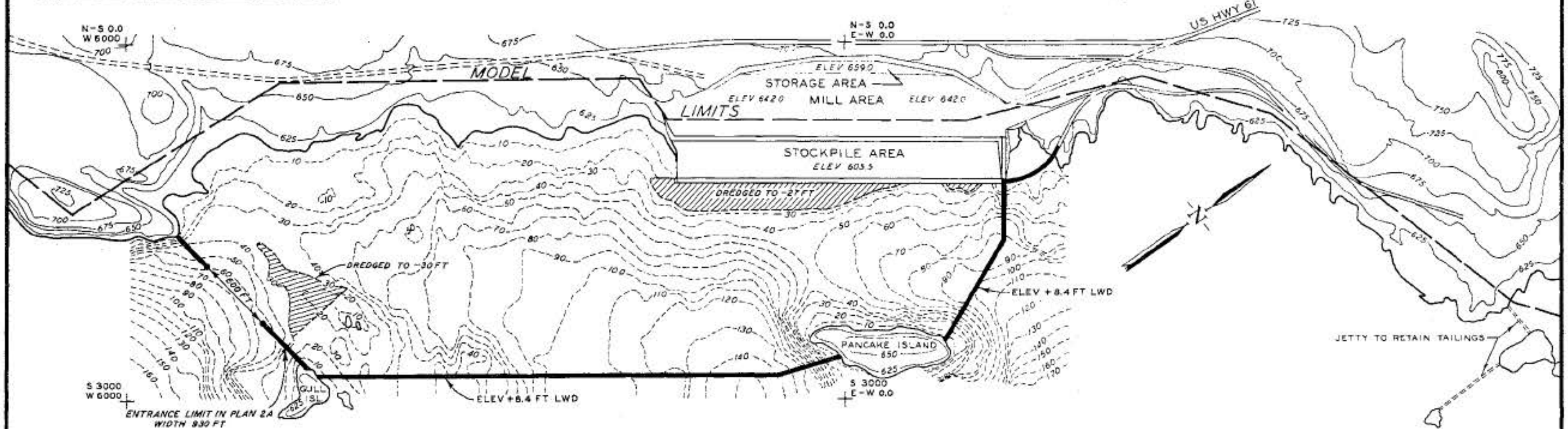
SCALES

PROTOTYPE 500 0 500 1000 1500 FT

MODEL 3 0 3 6 9 FT

PLATE 2





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LEGEND

PROPOSED RUBBLE-MOUND BREAKWATER

PROPOSED DREDGING. PROJECT DEPTHS AS SHOWN

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

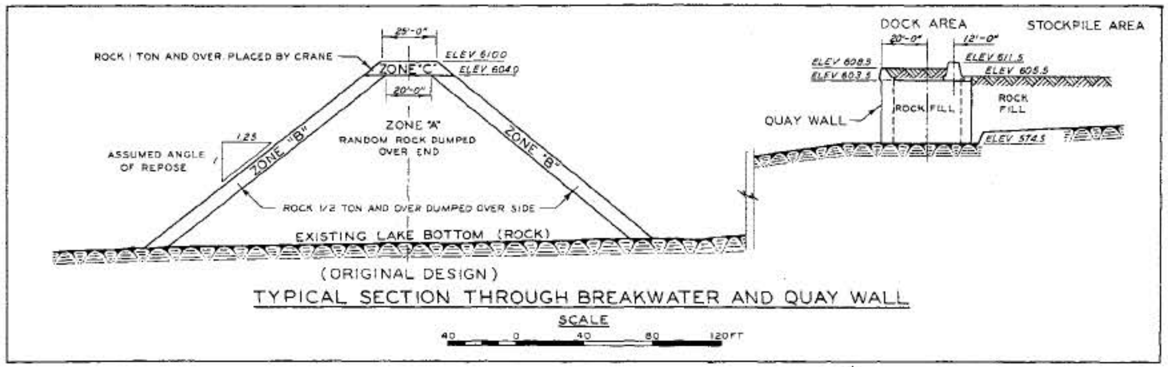
ELEMENTS OF PLANS 2 AND 2A

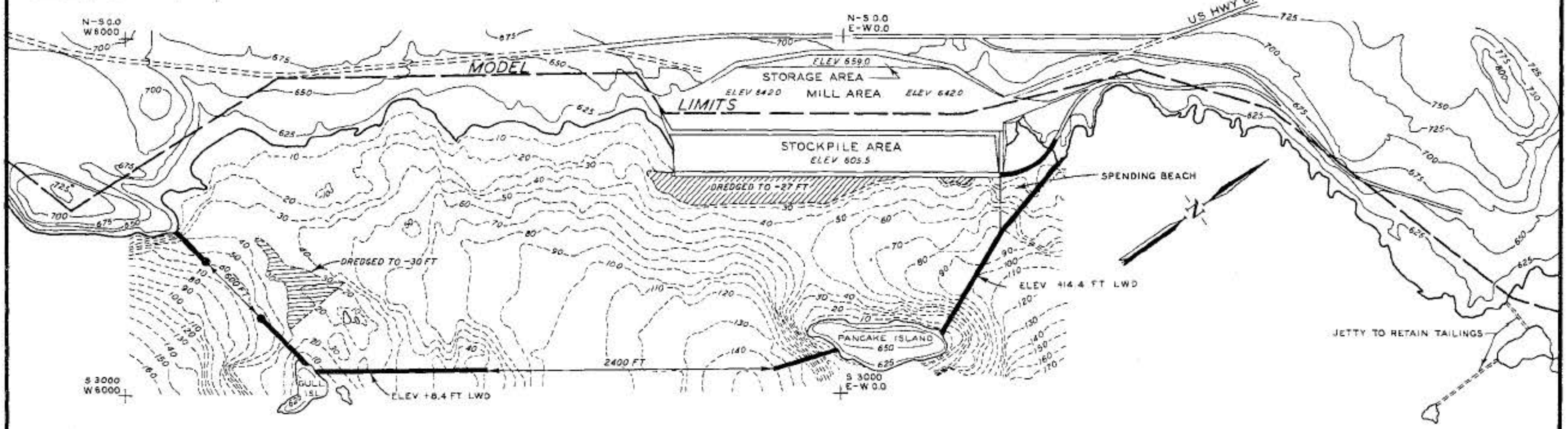
SCALES

PROTOTYPE 500 0 500 1000 1500 FT

MODEL 3 0 3 6 9 FT

PLATE 3





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LEGEND

PROPOSED RUBBLE-MOUND BREAKWATER

PROPOSED DREDGING, PROJECT DEPTHS AS SHOWN

TOE OF SPENDING BEACH

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

ELEMENTS OF PLAN 2B

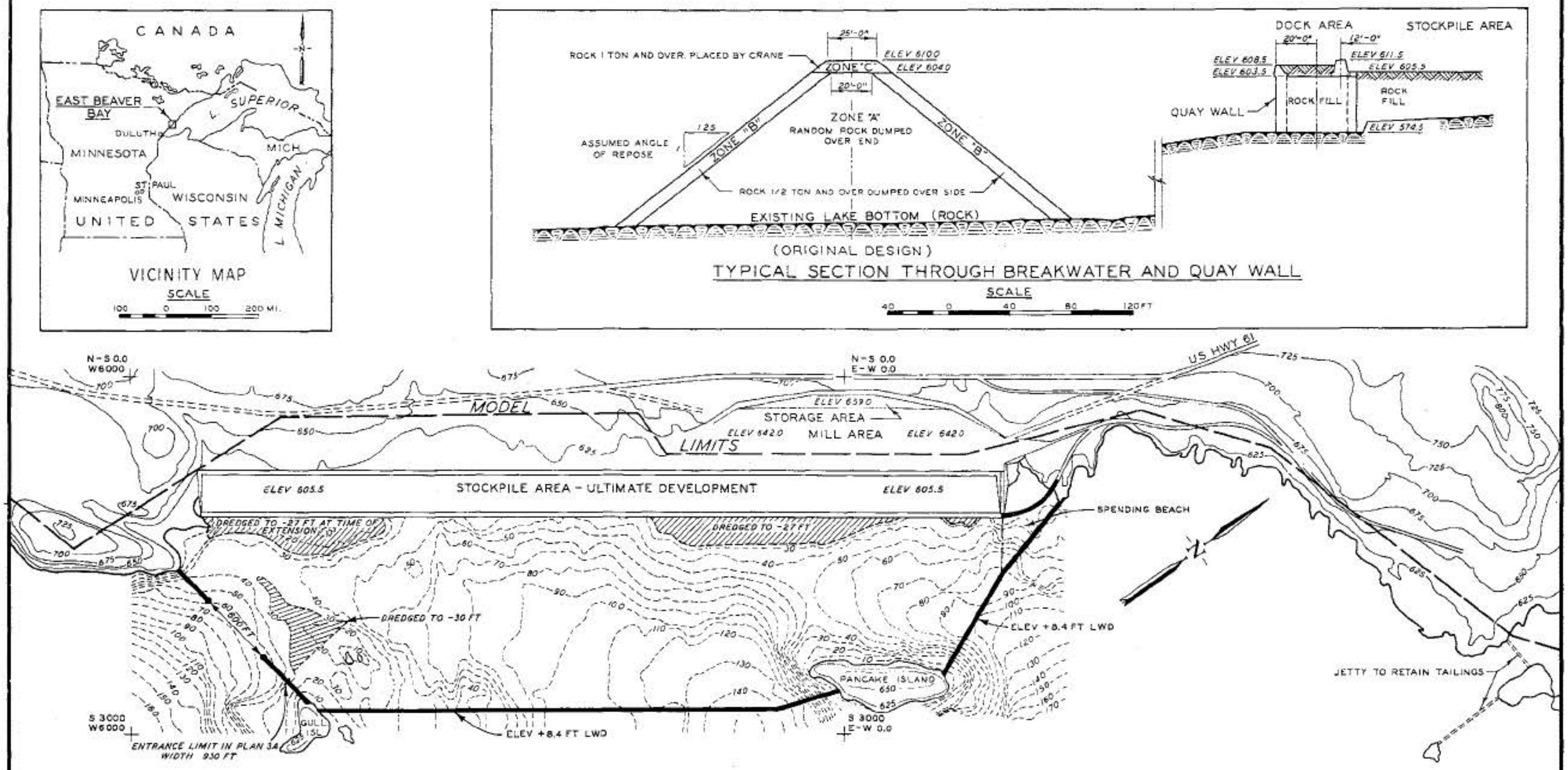
PARTIAL CONSTRUCTION

SCALES

PROTOTYPE 500 0 500 1000 1500 FT

MODEL 3 0 3 6 9 FT

PLATE 4



NOTE: HYDROGRAPHIC CONTOURS ARE IN FEET REFERRED TO LOW WATER DATUM (601.6 FT ABOVE MEAN TIDE AT NEW YORK CITY).

TOPOGRAPHIC CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN TIDE AT NEW YORK CITY.

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

LEGEND

PROPOSED RUBBLE-MOUND BREAKWATER

PROPOSED DREDGING PROJECT DEPTHS AS SHOWN

TOE OF SPENDING BEACH

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

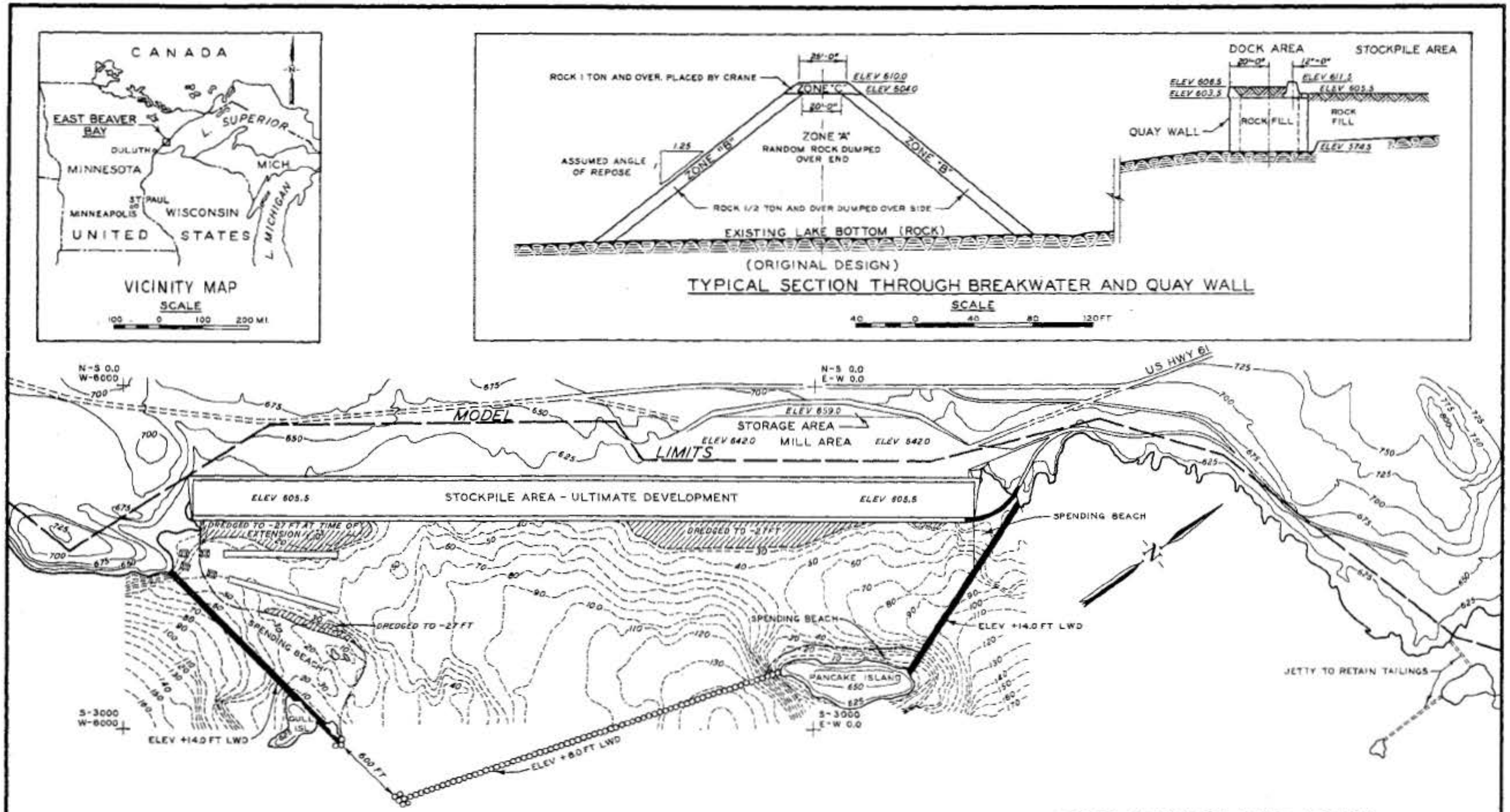
ELEMENTS OF PLANS 3 AND 3A

SCALES

PROTOTYPE 500 0 500 1000 1500 FT

MODEL 3 0 3 6 9 FT

PLATE 5



NOTE: HYDROGRAPHIC CONTOURS ARE IN FEET REFERRED TO LOW WATER DATUM (601.6 FT ABOVE MEAN TIDE AT NEW YORK CITY).

TOPOGRAPHIC CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MEAN TIDE AT NEW YORK CITY.

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

LEGEND

- PROPOSED RUBBLE-MOUND BREAKWATER
- PROPOSED CELLULAR BREAKWATER
- LOADING PIER
- PROPOSED DREDGING, PROJECT DEPTHS AS SHOWN
- TOE OF SPENDING BEACH

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

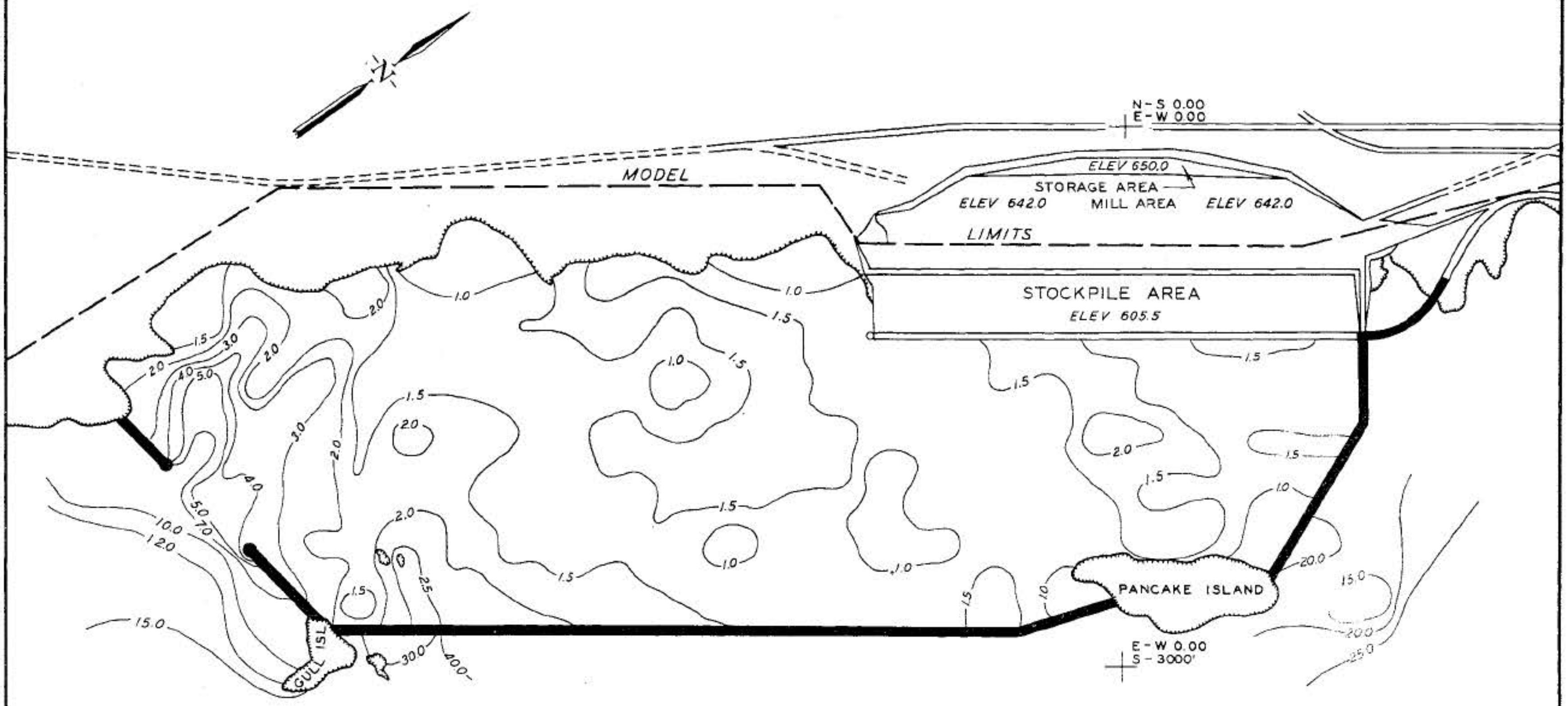
ELEMENTS OF PLAN 4

SCALES

PROTOTYPE 500 0 500 1000 1500 FT

MODEL 3 0 3 6 9 FT

PLATE 6



LEGEND

1.0 WAVE-HEIGHT CONTOUR IN FEET

PROPOSED BREAKWATER LOCATION

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +44 FT LWD
ENTRANCE WIDTH = 600 FT
PRIMARY WAVE HEIGHT = 22 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

WAVE HEIGHTS

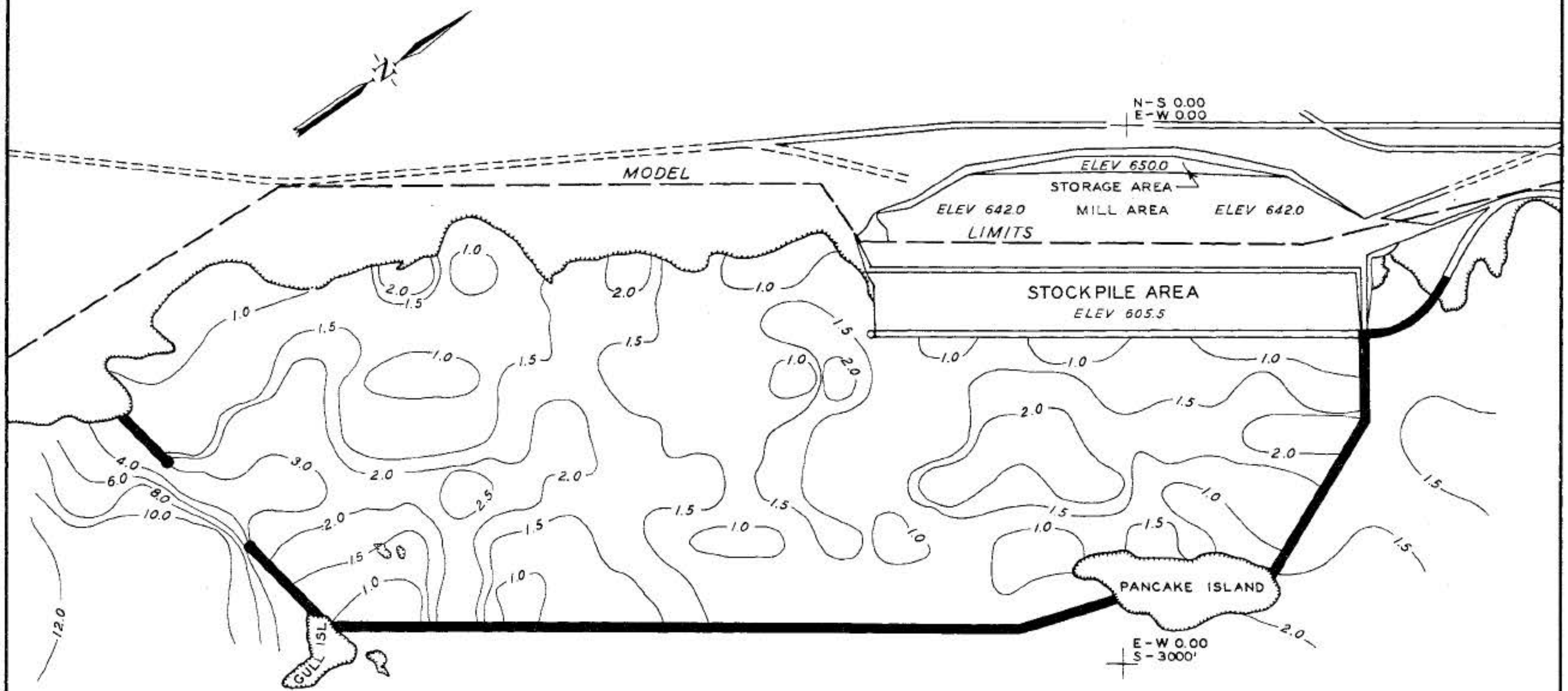
PLAN 2: 8.5 SEC WAVES FROM E BY N

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT

PLATE 7



LEGEND

~1.0~ WAVE-HEIGHT CONTOUR IN FEET

▬ PROPOSED BREAKWATER LOCATION

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +8.4 FT LWD
ENTRANCE WIDTH = 600 FT
PRIMARY WAVE HEIGHT = 12 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

WAVE HEIGHTS

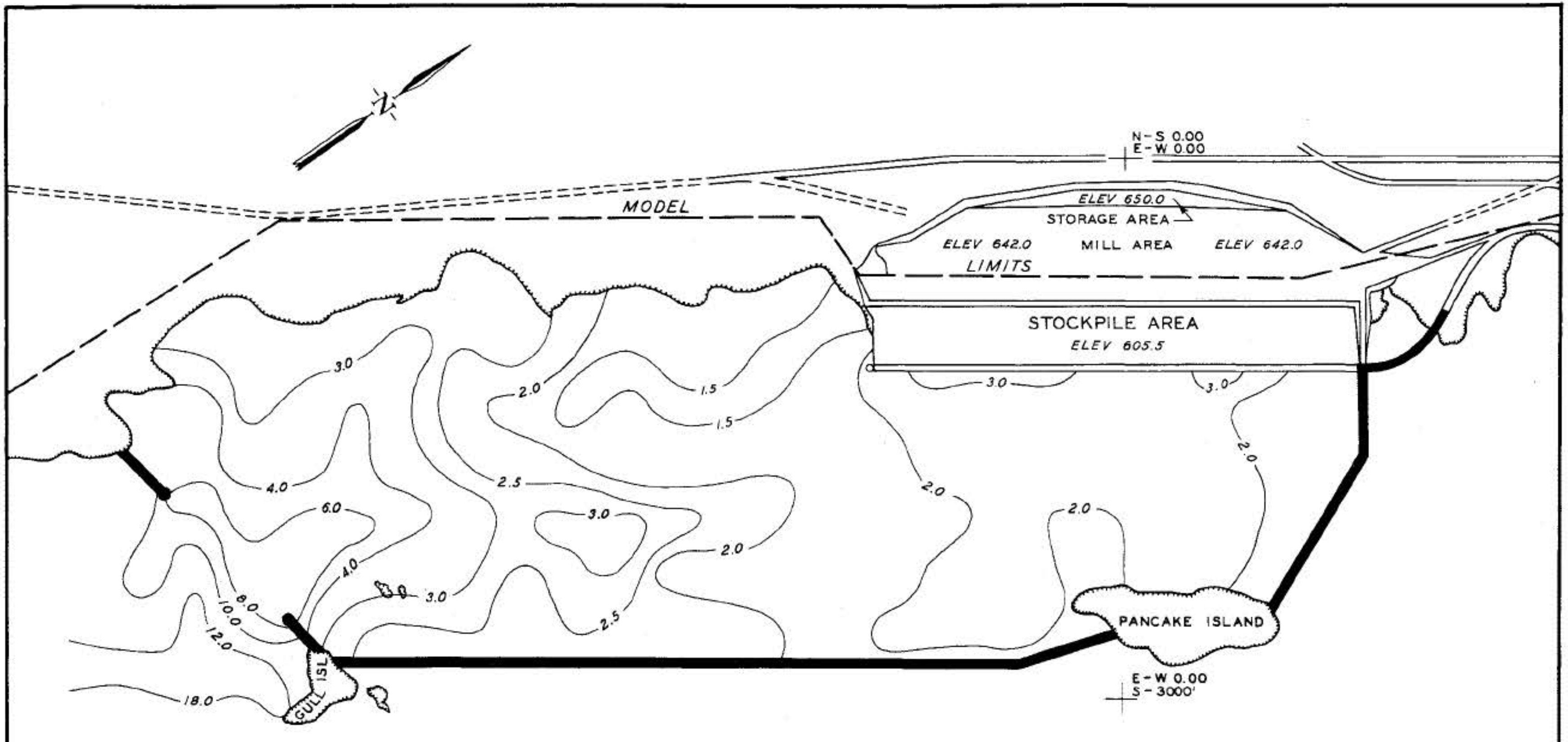
PLAN 2: 6 SEC WAVES FROM SW

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT

PLATE 8



LEGEND

WAVE-HEIGHT CONTOUR IN FEET

PROPOSED BREAKWATER LOCATION

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +44 FT LWD
ENTRANCE WIDTH = 930 FT
PRIMARY WAVE HEIGHT = 22 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

WAVE HEIGHTS

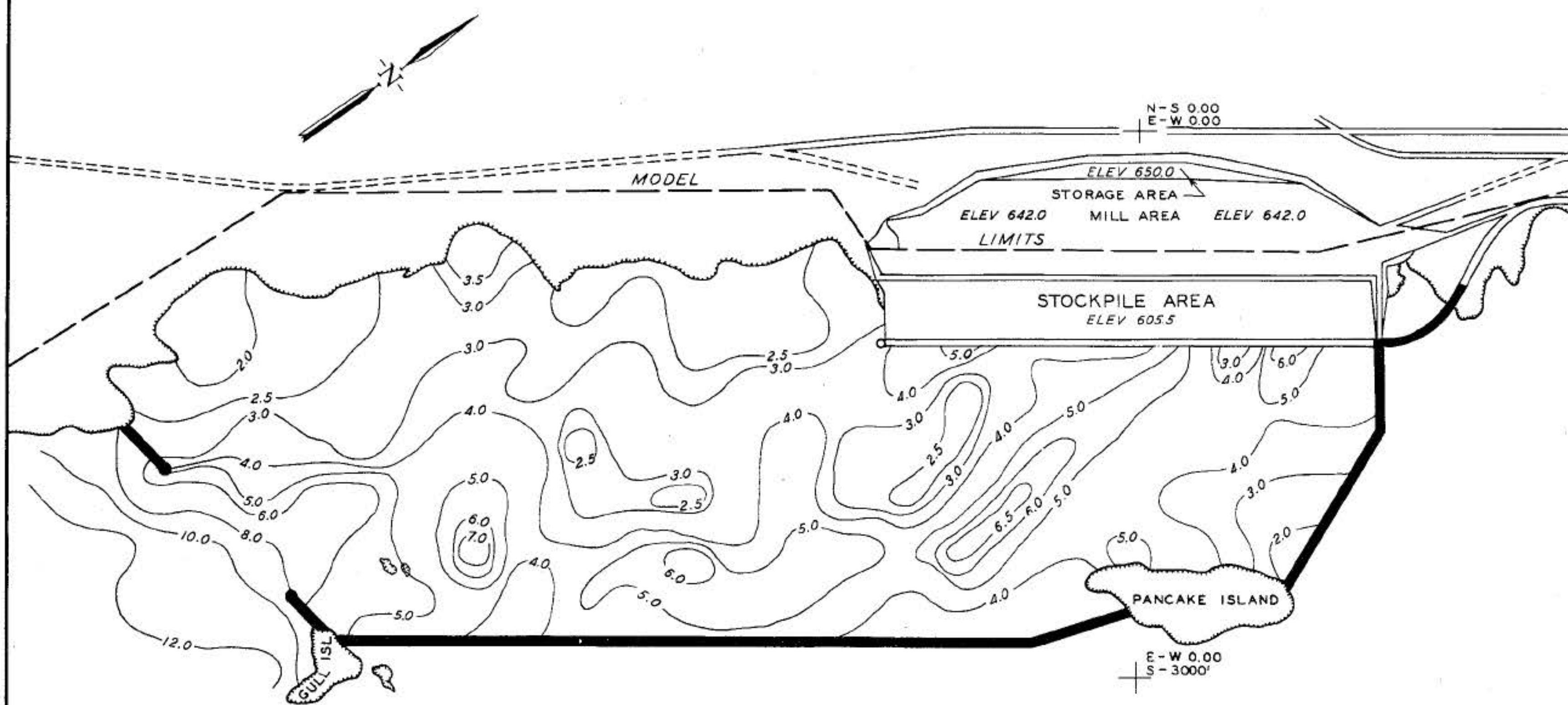
PLAN 2A: 8.5 SEC WAVES FROM E BY N

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT

PLATE 9



LEGEND

1.0 WAVE-HEIGHT CONTOUR IN FEET

PROPOSED BREAKWATER LOCATION

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +8.4 FT LWD
ENTRANCE WIDTH = 930 FT
PRIMARY WAVE HEIGHT = 12 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

WAVE HEIGHTS

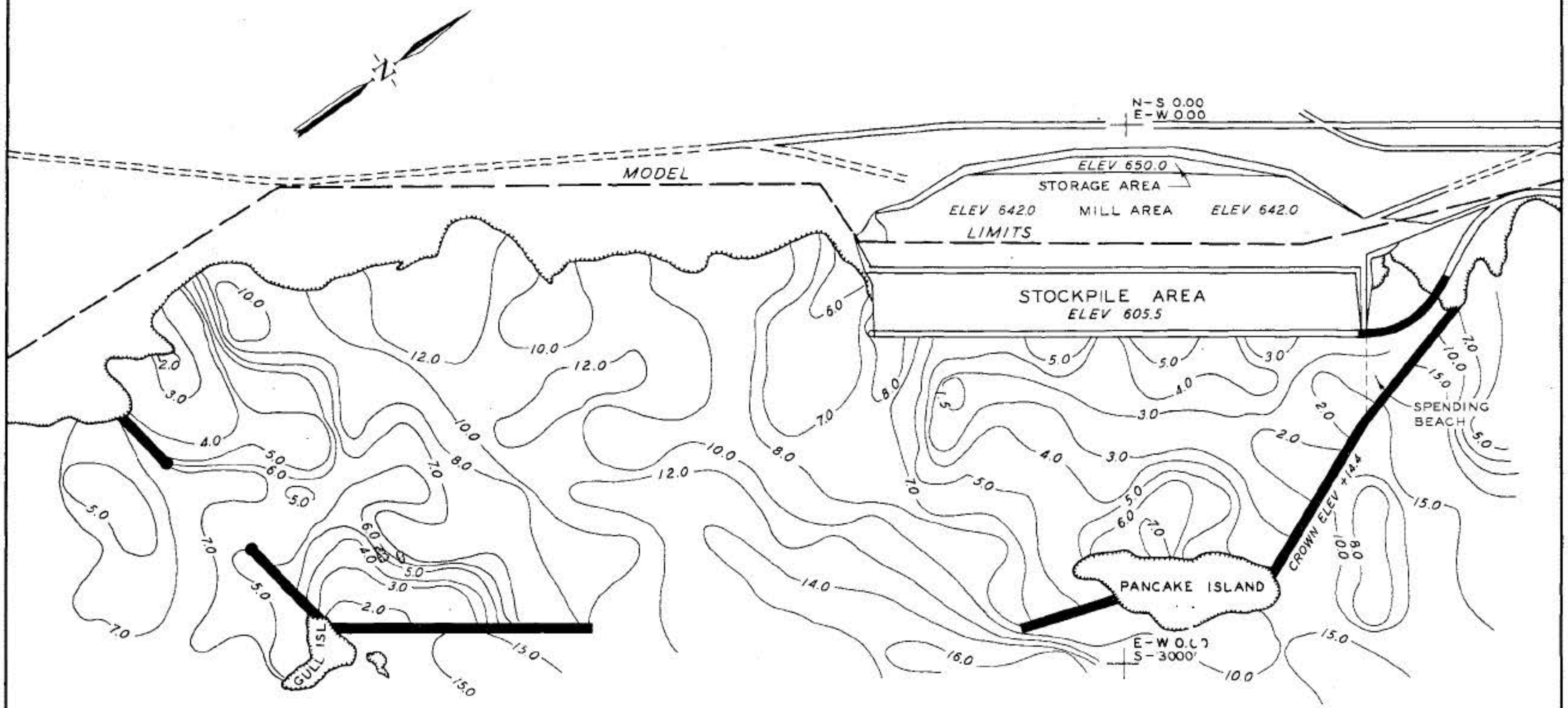
PLAN 2A: 6 SEC WAVES FROM SW

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT

PLATE 10



LEGEND

WAVE-HEIGHT CONTOUR IN FEET
PROPOSED BREAKWATER LOCATION
TOE OF SPENDING-BEACH SLOPE

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATIONS +8.4 & 14.4 FT LWD
ENTRANCE WIDTHS 600 & 2400 FT
PRIMARY WAVE HEIGHT = 8 FT

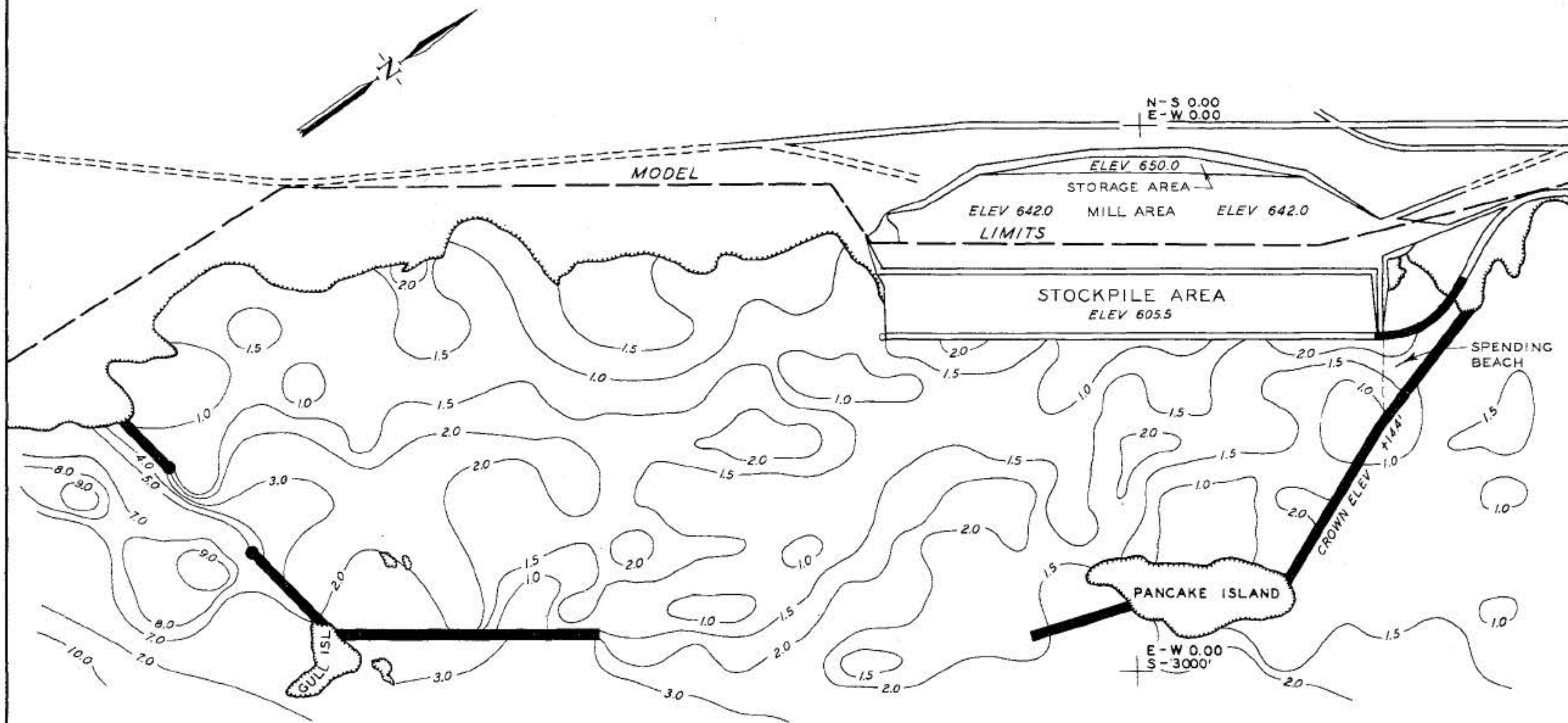
MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

WAVE HEIGHTS

PLAN 2B: 8.5 SEC WAVES FROM E BY N
PARTIAL CONSTRUCTION

SCALES

PROTOTYPE 400 0 400 800 FT
MODEL 2 0 2 4 FT



LEGEND

1.0 WAVE-HEIGHT CONTOUR IN FEET

PROPOSED BREAKWATER LOCATION

TOE OF SPENDING-BEACH SLOPE

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATIONS = +8.4 & 14.4 FT LWD
ENTRANCE WIDTHS = 600 & 2400 FT
PRIMARY WAVE HEIGHT = 6 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

WAVE HEIGHTS

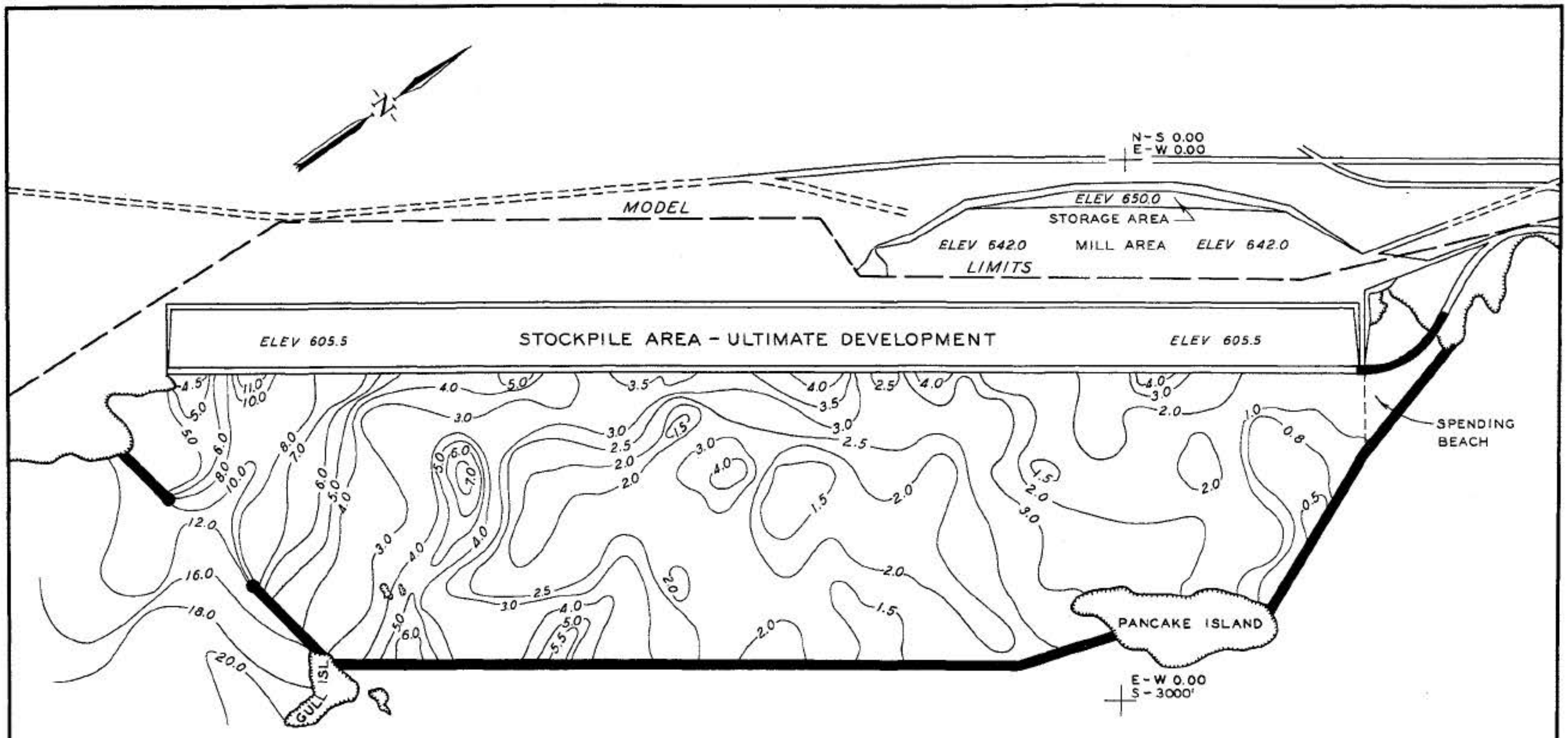
PLAN 2B: 6 SEC WAVES FROM SW
PARTIAL CONSTRUCTION

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT

PLATE 12



LEGEND

WAVE-HEIGHT CONTOUR IN FEET

PROPOSED BREAKWATER LOCATION

TOE OF SPENDING-BEACH SLOPE

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = + 1.5 FT LWD
CROWN ELEVATION = + 44 FT LWD
ENTRANCE WIDTH = 600 FT
PRIMARY WAVE HEIGHT = 22 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

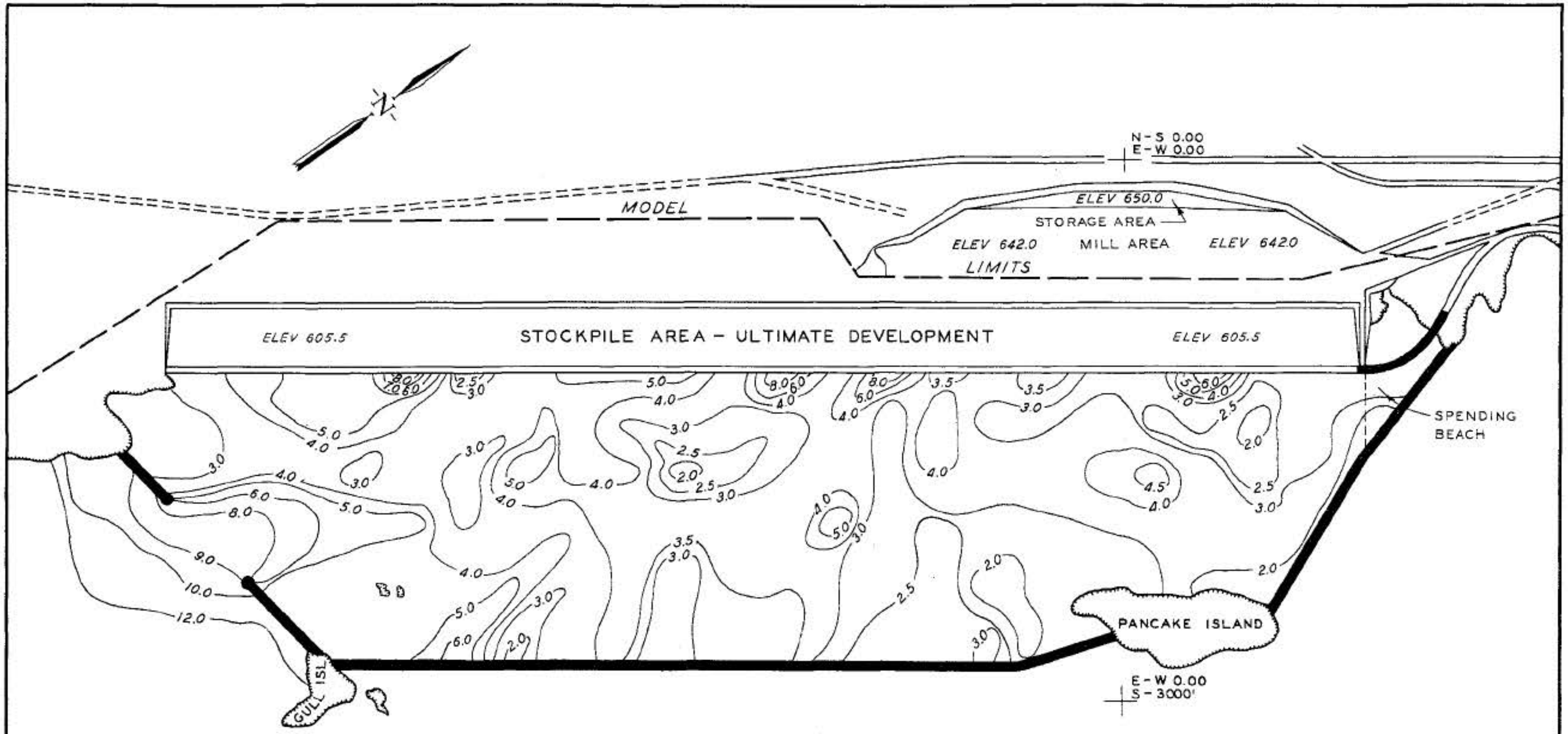
WAVE HEIGHTS

PLAN 3: 8.5 SEC WAVES FROM E BY N

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT



LEGEND

- 1.0 WAVE-HEIGHT CONTOUR IN FEET
- PROPOSED BREAKWATER LOCATION
- TOE OF SPENDING-BEACH SLOPE

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +8.4 FT LWD
ENTRANCE WIDTH = 600 FT
PRIMARY WAVE HEIGHT = 12 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

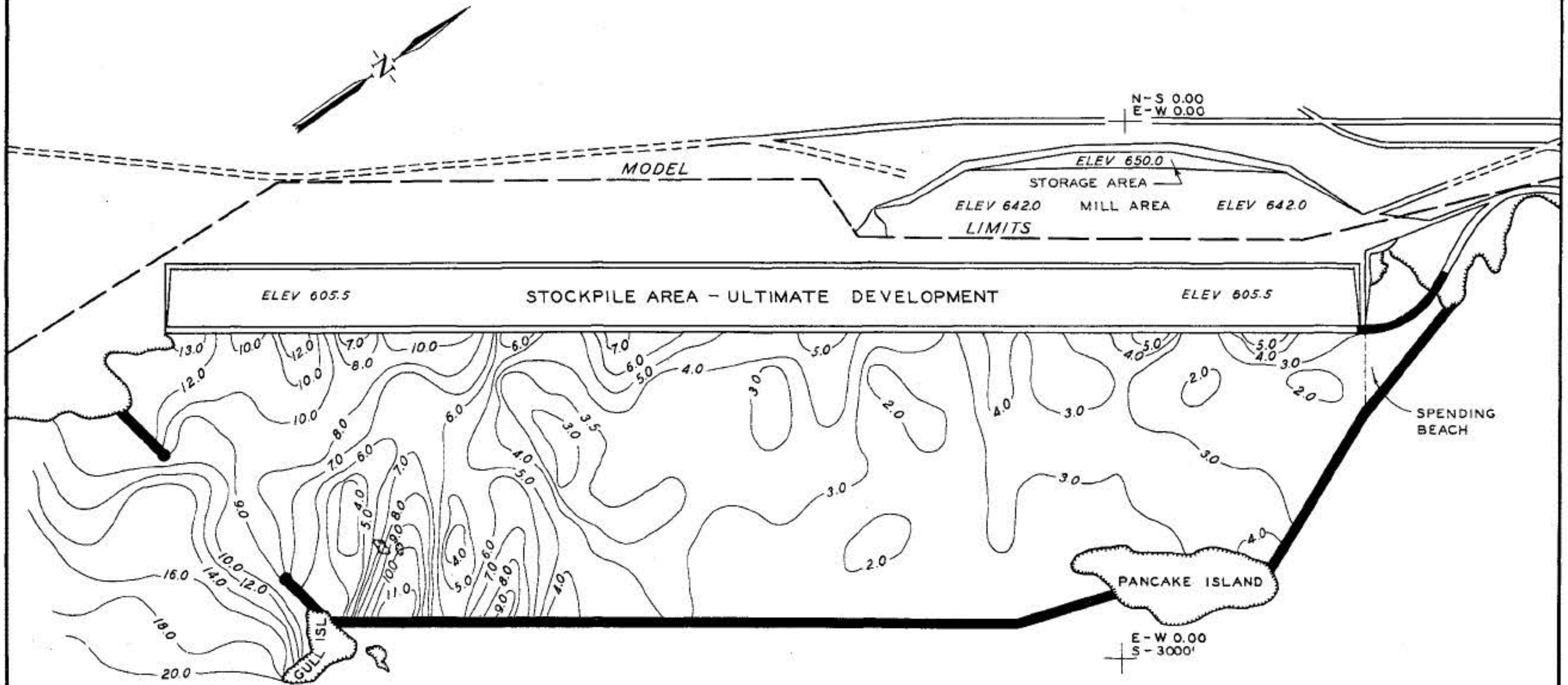
WAVE HEIGHTS

PLAN 3: 6 SEC WAVES FROM SW

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT



LEGEND

WAVE-HEIGHT CONTOUR IN FEET

PROPOSED BREAKWATER LOCATION

TOE OF SPENDING-BEACH SLOPE

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = + 44 FT LWD
ENTRANCE WIDTH = 930 FT
PRIMARY WAVE HEIGHT = 22 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

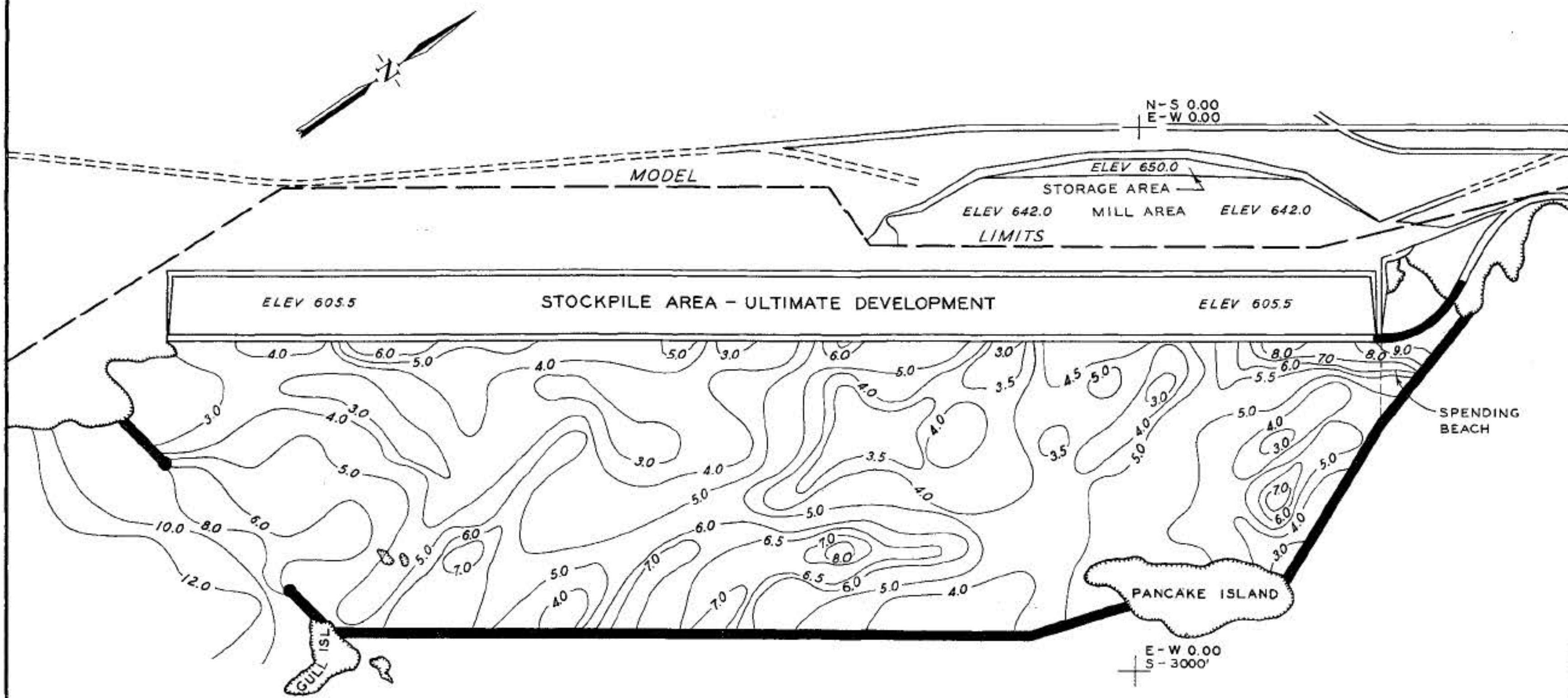
WAVE HEIGHTS

PLAN 3A: 8.5 SEC WAVES FROM E BY N

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT



LEGEND

1.0 WAVE-HEIGHT CONTOUR IN FEET

PROPOSED BREAKWATER LOCATION

TOE OF SPENDING-BEACH SLOPE

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +8.4 FT LWD
ENTRANCE WIDTH = 930 FT
PRIMARY WAVE HEIGHT = 12 FT

MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

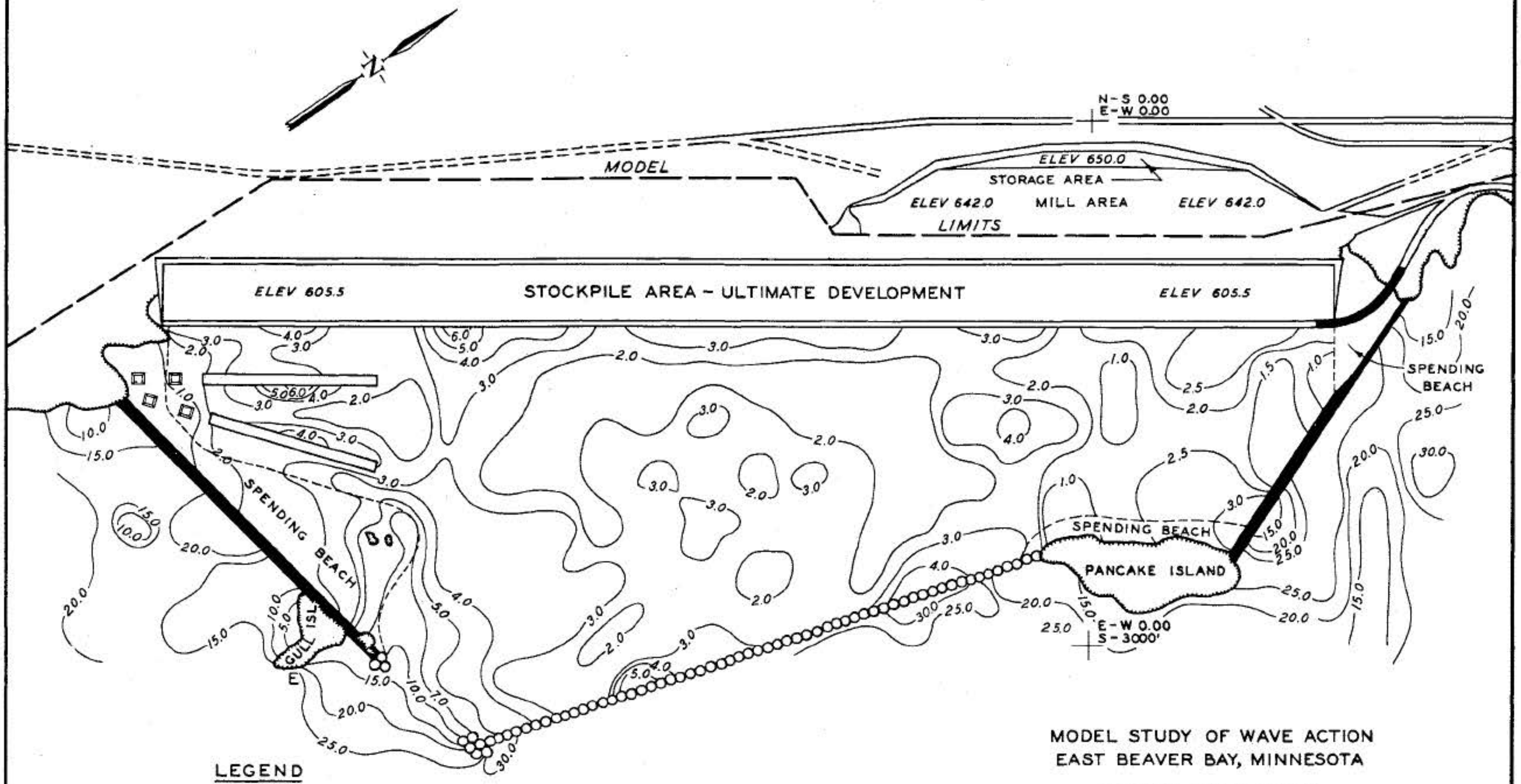
WAVE HEIGHTS

PLAN 3A: 6 SEC WAVES FROM SW

SCALES

PROTOTYPE 400 0 400 800 FT

MODEL 2 0 2 4 FT



MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA

WAVE HEIGHTS

PLAN 4: 8.5 SEC WAVES FROM E BY N

LEGEND

- 1.0 — WAVE-HEIGHT CONTOUR IN FEET
- PROPOSED RUBBLE-MOUND BREAKWATER
- PROPOSED CELLULAR BREAKWATER
- TOE OF SPENDING-BEACH SLOPE
- LOADING PIER

PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.

NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +44 FT LWD
ENTRANCE WIDTH = 600 FT
PRIMARY WAVE HEIGHT = 22 FT

SCALES

PROTOTYPE 400 0 400 800 FT
MODEL 2 0 2 4 FT

PLATE 17

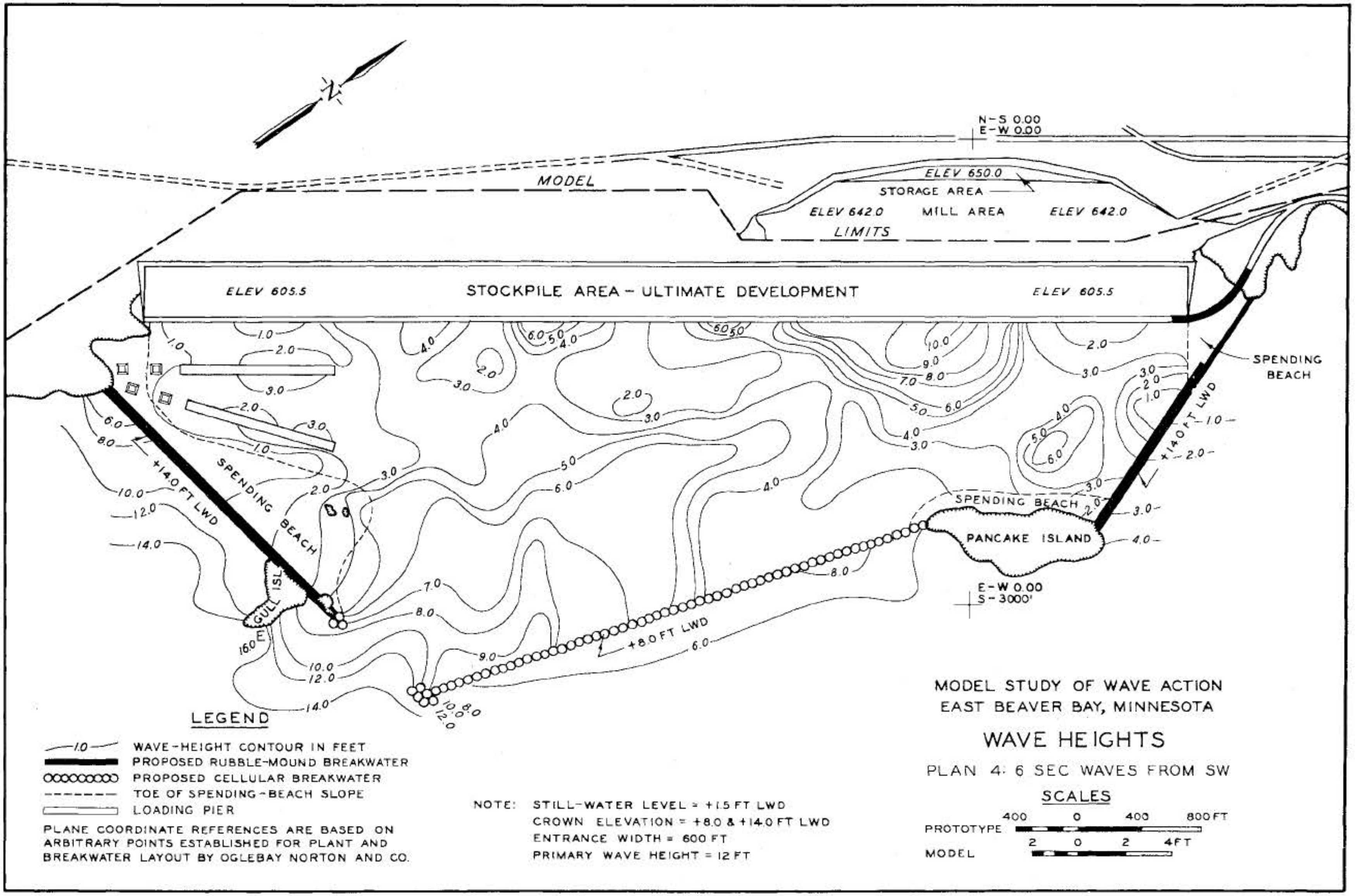

N
N-S 0.00
E-W 0.00
MODEL
LIMITS
ELEV 650.0
STORAGE AREA
ELEV 642.0
MILL AREA
ELEV 642.0
ELEV 605.5
STOCKPILE AREA – ULTIMATE DEVELOPMENT
ELEV 605.5
SPENDING BEACH
+14.0 FT LWD
SPENDING BEACH
+14.0 FT LWD
GULL ISL
SPENDING BEACH
PANCAKE ISLAND
+8.0 FT LWD
E-W 0.00
S-3000'
MODEL STUDY OF WAVE ACTION
EAST BEAVER BAY, MINNESOTA
WAVE HEIGHTS
PLAN 4: 6 SEC WAVES FROM SW
LEGEND
1.0 WAVE-HEIGHT CONTOUR IN FEET
PROPOSED RUBBLE-MOUND BREAKWATER
PROPOSED CELLULAR BREAKWATER
TOE OF SPENDING-BEACH SLOPE
LOADING PIER
PLANE COORDINATE REFERENCES ARE BASED ON ARBITRARY POINTS ESTABLISHED FOR PLANT AND BREAKWATER LAYOUT BY OGLEBAY NORTON AND CO.
NOTE: STILL-WATER LEVEL = +1.5 FT LWD
CROWN ELEVATION = +8.0 & +14.0 FT LWD
ENTRANCE WIDTH = 600 FT
PRIMARY WAVE HEIGHT = 12 FT
SCALES
PROTOTYPE 400 0 400 800 FT
MODEL 2 0 2 4 FT

PLATE 18